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Determination of Constant Optics of the Thin Films by the RT Method

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Abstract: In this study we present a method for determining the refractive index, absorption coefficient and thickness of thin films using a reflectance and transmittance of incident light (RT method). An algorithm is proposed, developed and tested for the calculation of the optical constants into the visible. Abacuses are traces in order to determiner this constant optics.

Key words: Optical properties, theoretical calculation of optical constants, algorithm, spectrophotometer

INTRODUCTION

The extraordinary development of high power lasers as well as the strong demand for optical filters imposed on the technology of surface coating a perfect knowledge of the optical parameters which determine qualities of the thin films[1]. The coatings are based on the phenomenon of interference. Knowledge of the optical parameters such as the real part of refractive index n and coefficient absorption k as well as the thickness d of thin films are essential for comparison of samples witch are produced using different methods and in different laboratories. These optical parameters are usually determined by photometric and ellipsometric methods[1-5]. Another method for the determination of the refraction index (n, k) and d is proposed, respectively, by using measurements of reflectivity and transmittance[6-8]. In this study, we are interested in the determination of the refraction index (n_1) and the absorption coefficient (k_1) as well as the thickness of the thin layer d_1 of a dielectric material or absorbent. This latter is deposited on a substrate (index n_2, of coefficient k_2 and thickness d_2 are known), by the technique of spectrophotometry[9] and especially by R-T method. Our approach is theoretical. It is based on the development of a calculation program to trace abacuses, which will enable us to determine any parameter (index, coefficient or thickness of the thin layer).

The algorithm is a global, robust and stochastic search method and we demonstrate that it provides a desirable solution for the determination of the complex refractive index of a thin film deposited on a transparent substrate using the optical reflection spectrum[10].

Basic equations and theory: Spectrometry is by far the most widely used technique for the determination of optical constants quoted previously. It consists in determining the reflectance R and transmittance T of the sample represented in Fig. 1 and the geometry of the measurements is shown in the same figure, where the

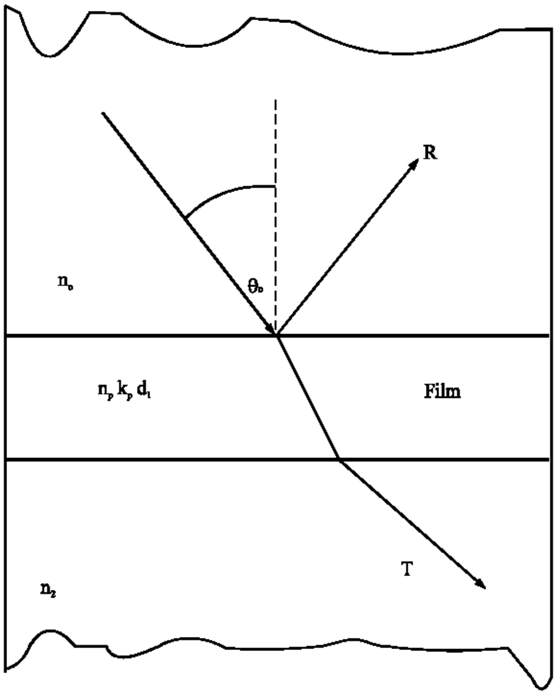

Fig. 1: Geometry of measurement, the film is facing the illuminating beam

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sample is illuminated by an s- or p polarized beam of wavelength λ at angle Θ_0 to the normal. We first measure the reflectance R and the transmittance T with film facing the light source.

We have a three-layered optical system: the medium on the top is labeled as medium zero, the thin film layer is labeled as medium one and the medium on the bottom is labeled as medium two; the angle of incidence Θ_0 is measured in medium zero; R is the reflectance and T is the transmittance Fig. 1.

The formulas from Fresnel Eq. 7 allow the determination:

For the reflection

$$R = \frac{\left|r_1\right|^2 + \left|r_2\right|^2 + 2\left|r_1\right|\left|r_2\right| \cos 2\delta}{1 + \left|r_1\right|^2 + \left|r_2\right|^2 + 2\left|r_1\right|\left|r_2\right| \cos 2\delta} \tag{1}$$

Where

$$\delta = 2?\ \mathrm{In}\ d/\lambda \tag{2}$$

$$\left|r_1\right| = \sqrt{g_0^2 + h_0^2} \quad \left|r_2\right| = \sqrt{g_1^2 + h_1^2} \tag{3}$$

And:

$$\begin{cases} g_0 = \dfrac{n_0^2 \cos^2\theta_0 - \left(n_1^2 + \kappa_1^2\right)\cos^2\theta_1}{\left(n_0 \cos\theta_0 + n_1 \cos\theta_1\right)^2 + \kappa_1^2 \cos^2\theta_1} \\ h_0 = \dfrac{2\, n_1 k_1 \cos\theta_0 \cos\theta_1}{\left(n_0 \cos\theta_0 + n_1 \cos\theta_1\right)^2 + \kappa_1^2 \cos^2\theta_1} \end{cases} \tag{4}$$

$$\begin{cases} g_1 = \dfrac{\left(n_1^2 + k_1^2\right)\cos^2\theta_1 - \left(n_2^2 + \kappa_2^2\right)\cos^2\theta_2}{\left(n_1 \cos\theta_1 + n_2 \cos\theta_2\right)^2 + \left(\kappa_1 \cos\theta_1 + \kappa_2 \cos\theta_2\right)^2} \\ h_1 = \dfrac{2\left(n_1 k_1 - n_2 k_2\right) \cos\theta_1 \cos\theta_2}{\left(n_1 \cos\theta_1 + n_2 \cos\theta_2\right)^2 + \left(\kappa_1 \cos\theta_1 + \kappa_2 \cos\theta_2\right)^2} \end{cases} \tag{5}$$

For the transmission:

$$T = \frac{n_1 \cos\theta_1}{n_0 \cos\theta_0} \frac{t_1^2\, t_2^2}{1 + r_1^2 + r_2^2 + 2\, r_1 r_2 \cos 2\delta} \tag{6}$$

It is convenient to introduce the following parameters

$$x = g_0^2 + h_0^2,\ y = g_1^2 + h_1^2 \tag{7}$$

With

$$Z = \left(\mathrm{Re}_0^2 + \mathrm{Im}_0^2\right)^2 \left(\mathrm{Re}_1^2 + \mathrm{Im}_1^2\right)^2 \tag{8}$$

By replacing the Eq. 7 and 8 in Eq. 6, it becomes:

$$T = \frac{n_1 \cos\theta_1}{n_0 \cos\theta_0} \frac{Z}{1 + x + y + 2\sqrt{x \times y}\cos 2\delta} \tag{9}$$

Where

$$\mathrm{Re}_0 = \frac{2\left(n_0^2 \cos^2\theta_0\right) - n_0 n_1 \cos\theta_0 \cos\theta_1}{\left(n_0 \cos\theta_0 + n_1 \cos\theta_1\right)^2 + k_1^2 \cos^2\theta_1} \tag{10}$$

$$\mathrm{Im}_0 = \frac{2 n_0 k_0 \cos\theta_0 \cos\theta_1}{\left(n_0 \cos\theta_0 + n_1 \cos\theta_1\right)^2 + k_1^2 \cos^2} \tag{11}$$

In the same way

$$\mathrm{Re}_1 = \frac{2\left(n_1^2 + k_1^2\right)\cos^2\theta_1 - \left(n_1 n_2 + k_1 k_2\right)\cos\theta_1 \cos\theta_2}{\left(n_1 \cos\theta_1 + n_2 \cos\theta_2\right)^2 + \left(\kappa_1 \cos\theta_1 + \kappa_2 \cos\theta_2\right)^2} \tag{12}$$

$$\mathrm{Im}_1 = \frac{2\left(n_1 \kappa_2 - n_2 \kappa_1\right)\cos\theta_1 \cos\theta_2}{\left(n_1 \cos\theta_1 + n_2 \cos\theta_2\right)^2 + \left(\kappa_1 \cos\theta_1 + \kappa_2 \cos\theta_2\right)^2} \tag{13}$$

We can draw d_1 like function from the other parameters:

$$d_{1=} \frac{\lambda}{4.\pi.n_1} \mathrm{arcco} \frac{n_2 \cdot \left|t_1\right|^2 \cdot \left|t_2\right|^2 - \frac{T}{R}\left(\left|r_1\right|^2 + \left|r_2\right|^2\right)}{2\left|r_1\right| \cdot \left|r_2\right| \frac{T}{R}} \tag{14}$$

FLOW CHART OF CALCULATION

The complexity of calculation requires developing a flow chart of calculation which makes possible to calculate the factors of the reflexion and the transmission

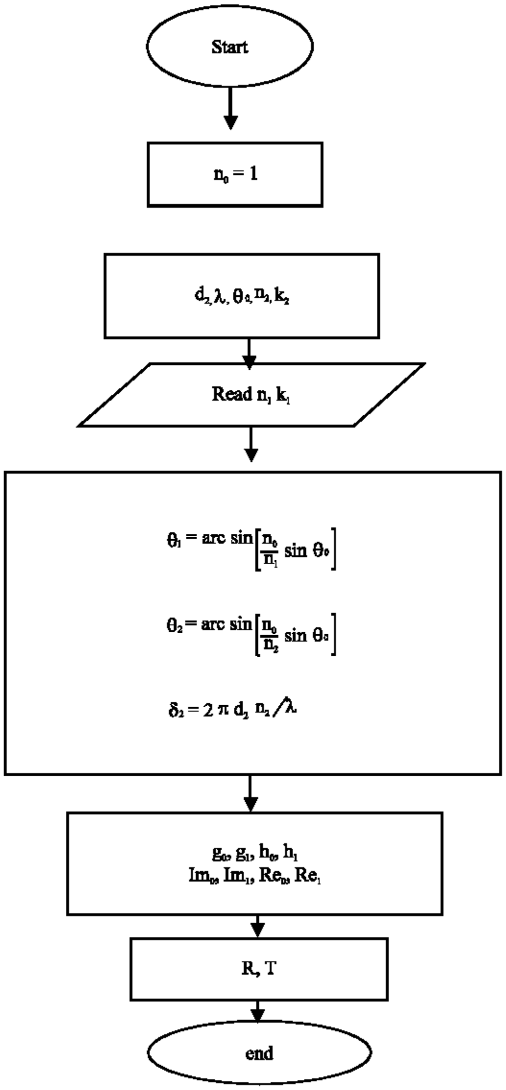

Fig. 2: The flow-chart of the implemented genetic algorithm

of a thin layer under incidence θ_0. After having calculated these constants, the programmer makes possible to trace abacuses which directly give the values of optical constants (n_1, k_1) for a thin layer where the factors of transmission and of reflection are known. It also makes possible to include the influence of the various parameters (d_2, λ, n_2, k_2, θ_0) on the optical proprieties of the layer.

RESULTS AND DISCOSSION

The results of this program are given by Fig. 3, 4 and 5. Figure 3 illustrates the variation of the coefficient of transmission T with the index of refraction n_1 for two different wavelengths and the value $d_2 = 600$ nm; $k_2 = 1.5$; $n_2 = 2.5$ and $\theta_0 = 45°$.

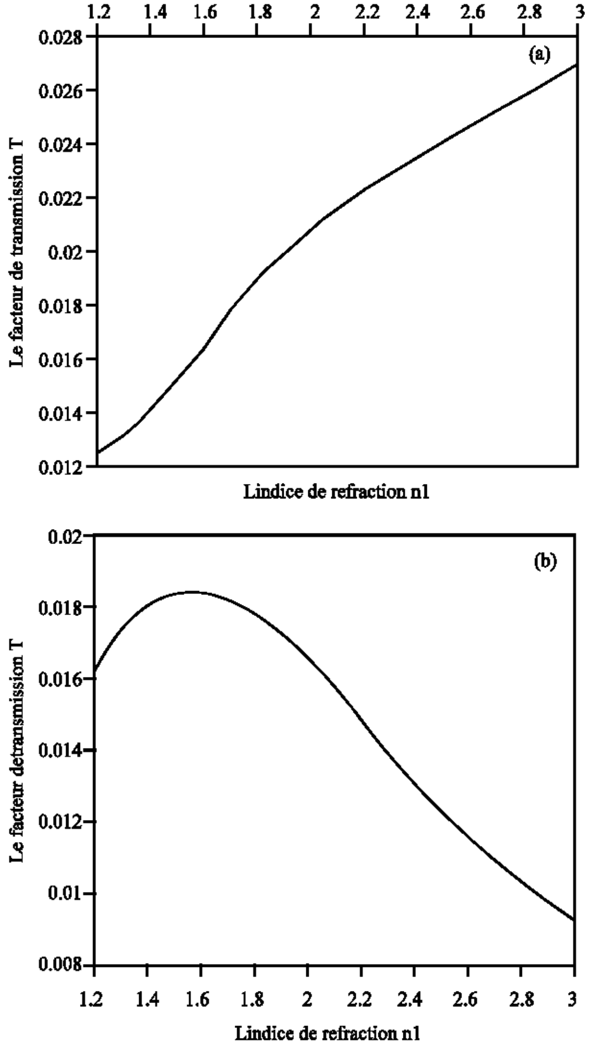

Fig. 3: Variation of T according to n_1 a) $\lambda = 400$ nm, b) $\lambda = 600$ nm

On the other hand Fig. 4 and 5, respectively represent the variations of these same factors according to the thickness of the substrate and its absorption coefficient. The abacuses of figure 6 represent the variation of transmittance and reflectance according to the absorption coefficient and that for several wavelengths. All these curves enable us to determine the various optical constants of the thin layer while measuring either, its reflectance or, its transmittance if constant optics of the substrate is known as well as the wavelength and the angle of incidence. The results obtained are usable whatever the material deposited and for any type of substrate.

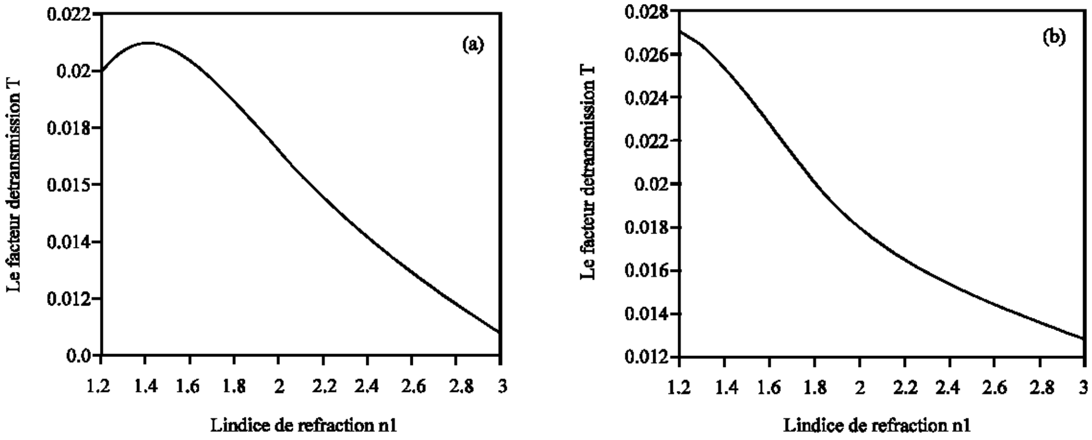

Fig. 4: Variation of T according to n1 a) d_2 = 100 nm, b) d_2 = 30 nm

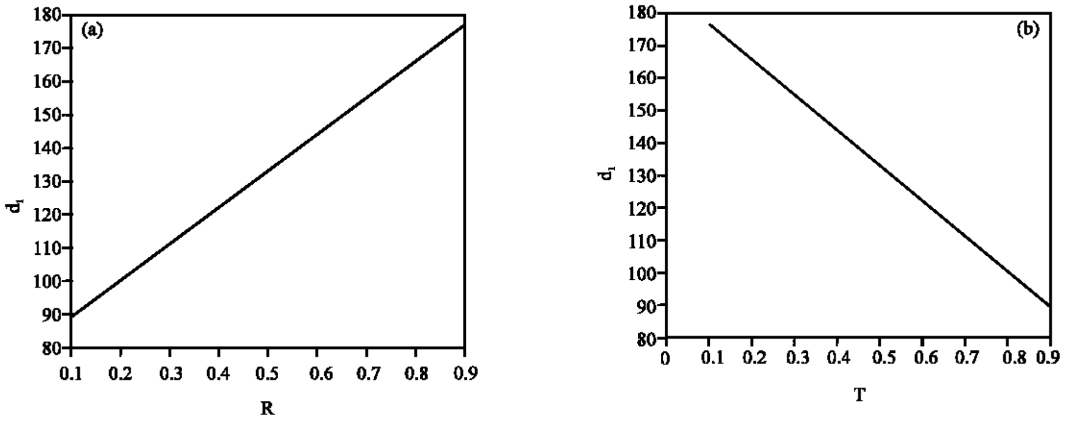

Fig. 5: Variation of the coefficients of reflexion and transmission with thickness of the layer

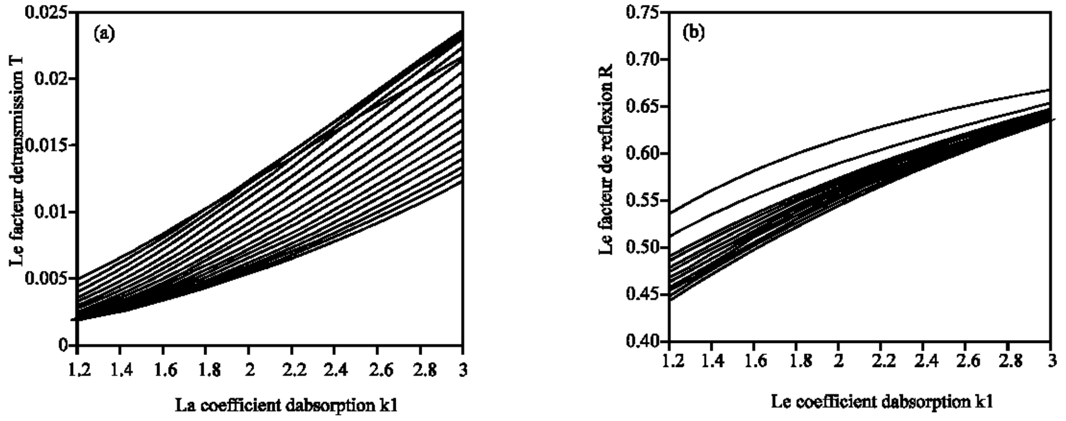

Fig. 6: a) Coefficient of transmission, b) coefficient of reflection according to the absorption coefficient of the layer for various wavelengths (400 to 700) nm

CONCLUSION

In this study, we have traced abacuses which enable us to come up with required optical constants. The method used is a rather simple technique which, consists of measuring the variation of the factors of reflection and transmission of a thin layer, using a spectrophotometer, with the wavelength. These factors are then used, to determine, using the abacuses, suitable corresponding optical constants.

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